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ORIGINAL ARTICLE

A risk profile for identifying community-dwelling elderly with a high risk of recurrent falling: results of a 3-year prospective study

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Abstract *Introduction:* The aim of the prospective study reported here was to develop a risk profile that can be used to identify community-dwelling elderly at a high risk of recurrent falling. *Materials and methods:* The study was designed as a 3-year prospective cohort study. A total of 1365 community-dwelling persons, aged 65 years and older, of the population-based Longitudinal Aging Study Amsterdam participated in the study. During an interview in 1995/1996, physical, cognitive, emotional and social aspects of functioning were assessed. A follow-up on the number of falls and fractures was conducted during a 3-year period using fall calendars that participants filled out weekly. Recurrent fallers were identified as those who fell at least twice within a 6-month period during the 3-year follow-up. *Results:* The incidence of recurrent falls at the 3-year follow-up point was 24.9% in women and 24.4% in men. Of the respondents, 5.5% reported a total of 87 fractures that resulted from a fall, including 20 hip fractures, 21 wrist fractures and seven humerus fractures. Recurrent fallers were more prone to have a fall-related fracture than those who were not defined as recurrent fallers (11.9% vs. 3.4%; OR: 3.8; 95% CI: 2.3–6.1). Backward logistic regression analysis identified the following predictors in the risk profile for recurrent falling: two or more previous falls, dizziness, functional limitations, weak grip strength, low body weight, fear of falling, the presence of dogs/cats in the household, a high educational level, drinking 18 or more alcoholic consumptions per week and two interaction terms (high education×18 or more alcohol consumptions per week and two or more previous falls × fear of falling) (AUC=0.71). *Discussion:* At a cut-off point of 5 on the total risk score (range 0–30), the model predicted recurrent falling with a sensitivity of 59% and a specificity of 71%. At a cut-off point of 10, the sensitivity and specificity were 31% and 92%, respectively. A risk profile including nine predictors that can easily be assessed seems to be a useful tool for the identification of community-dwelling elderly with a high risk of recurrent falling.

Keywords Accidental falls · Aged · Cohort study · Community-dwelling · Fractures · Risk assessment

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Introduction

Falls are a serious public health problem in the elderly because they occur frequently and may have severe consequences [1–4]. Of the people over the age of 65 who live in the community, 30% fall at least once a year [5–7]. These falls can result in serious injuries, such as fracture and head trauma [5, 6, 8], and may cause a fear of falling [1–3]. Ten percent of all falls result in a major injury, of which 1% are hip fractures and 5% are other fractures [6]. Ninety percent of all fractures are attributable to falls, the most common of which is from standing height or less [9]. Moreover, fall-related injuries are the third leading cause of years lived with disability according to the WHO report "Global burden of disease" [4]. These serious consequences emphasise the need to implement strategies to decrease the burden of falls in older people. Intervention studies have shown that a multiple risk factor intervention strategy targeted at both intrinsic and environmental risk factors can reduce the risk of falling by 10–25% [10–13]. Preventive measures may be most effective when they are focussed on those older people with an increased risk of falls [14, 15], but in order to identify the community-dwelling elderly at risk of recurrent falling, a valid and feasible risk profile is needed.

Epidemiological studies have identified various risk factors as predictors of falls among community-dwelling elderly. The most important of these appears to be a history of falling and specific chronic diseases, including osteoarthritis, impaired mobility and balance and muscle weakness [5–8, 16–19]. Based on these predictors, several investigators have made efforts to construct risk profiles to identify community-dwelling elderly with a high risk of falling [5–8, 16–18]. However, the studies in which these risk profiles have been developed either had a short follow-up of 1 year maximum [6, 7, 17, 18], assessed the falls retrospectively [8] or used rather small study samples that were not representative of the general population of community-dwelling elderly [5, 6, 16–18].

The Longitudinal Aging Study is a large cohort study that includes older men and women that are representative of the more senior sector of the Dutch population. The aim of this study was to develop a risk profile that can be used to identify community-dwelling elderly at a high risk of recurrent falling using a 3-year fall follow-up.

Materials and methods

Sample

Data for this study were collected within the Longitudinal Aging Study Amsterdam (LASA), an ongoing interdisciplinary cohort study on predictors and consequences of changes in autonomy and well-being in the aging population in the Netherlands [20]. The sampling and data collection procedures have been described in more detail elsewhere [21, 22]. In brief, a sample of older men and women (aged 55–85 years), stratified by age and sex, was drawn from the population registries of 11 municipalities in three areas of The Netherlands. In total, 3107 subjects (response rate=81.7%) were enrolled in the baseline examination (1992/1993).

The present study was performed using a subsample of the LASA population, including respondents who participated in the second data collection cycle of LASA (1995/1996), were born in or before 1930 (aged 65 years and older as of January 1, 1996) and were living in the community. Following a main interview and a medical interview at home in which structured questionnaires were completed and tests were performed, participants were invited to the VU University Medical Center (VUmc) or a health care centre where blood and urine samples were obtained. After the 1995/1996 data collection cycle, a 3-year follow-up on falls was conducted.

The interviews were conducted by intensively trained and supervised non-medical interviewers. All interviews were tape-recorded in order to monitor the quality of the data [21]. Informed consent was obtained from all respondents, and the study was approved by the Medical Ethics Committee of the Vumc and conducted according to the principles of the Helsinki declaration.

Assessment of falls and fractures

The participants were asked to record fall and fracture events every week for 3 years on a ‘fall and fracture calendar’ and to mail the calendar page to the research institute at 3-month intervals. The participants were contacted by telephone if they were unable to complete the calendar, if the calendar was not returned even after a reminder or if it was completed incorrectly. Proxies were contacted if participants were not able to respond. In addition, during the third and fourth data collection cycles (1998/1999 and 2001/2002), information concerning fractures was collected retrospectively. The general practitioners (GP) of the respondents were asked to confirm the reported fractures, and if a respondent died, the GP was asked whether a fracture had occurred in the time interval following the last contact with the respondent. The GP was also asked to report whether the fracture was caused by a fall or by a (motor vehicle) accident.

A fall was defined as ‘an unintentional change in position resulting in coming to rest at a lower level or on the ground’ [23]. A ‘recurrent faller’ was defined as a subject who fell at least twice within a 6-month period during the 3-year fall follow-up [24, 25].

Predictors

During the second data collection cycle of LASA (1995/1996), several aspects of physical, cognitive, emotional and social functioning were assessed. The predictors of falls were based on a previous study carried out in homes for the elderly in The Netherlands [26] and on the literature [6, 16, 17]. Potential predictors were classified into nine categories: socio-demographic characteristics, chronic diseases and drug use, physical impairments and general health, body composition, physical activity and mobility, psychosocial functioning, life style factors, biochemical markers and other potentially fall-related predictors. All potential predictors of falls are presented in Table 1. Predictors that were included in the final risk profile (Table 2) are described in more detail below (descriptions of other predictors are available from the corresponding author upon request).

Level of education was assessed by asking the respondent for the highest educational level completed, ranging from primary to university education. The responses were converted into years of education (range: 5–18 years). A high educational level was defined as more than 10 years of education. Dizziness was assessed by asking whether the respondent was dizzy regularly (yes/no). Previous falls were

Table 1 Prevalence, univariate odds ratios (ORs) and 95% confidence intervals (CI) for potential predictors of recurrent falling (≥2 falls in a 6-month period) (n=1365)

Potential predictor variables[a]	Percentage	OR (95% CI)
Socio-demographic characteristics		
Age ≥ 80 years (vs. <80 years) (n=1365)	27.9	1.69 (1.30–2.19)
Women (vs. men) (n=1365)	51.1	1.08 (0.85–1.39)
Education ≥11 years (vs. <11 years) (n=1364)	28.0	1.36 (1.04–1.77)
Living in an highly urbanised area (n=1365)	28.4	1.43 (1.10–1.87)
Chronic diseases and medication use		
≥ One chronic disease (vs. < one disease) (n=1365)	72.9	1.43 (1.07–1.91)
Osteoarthritis (yes/no) (n=1365)	44.6	1.54 (1.20–1.97)
Medication use ≥ four drugs (vs. < four drugs) (n=1364)	24.6	1.51 (1.15–1.99)
Physical impairments and general health		
Involuntary loss of urine (yes/no) (n=1365)	24.1	1.76 (1.34–2.31)
Dizziness (yes/no) (n=1362)	14.7	2.05 (1.49–2.82)
Systolic blood pressure ≤ 133 mmHg (vs. >133 mmHg) (25th p) (n=1328)	24.6	1.26 (0.95–1.66)
Orthostatic hypotension (yes/no) (n=1337)	13.4	0.99 (0.68–1.42)[b]
Visual impairment (yes/no) (n=1361)	19.3	1.87 (1.40–2.50)
Hearing impairment (yes/no) (n=1364)	36.7	1.51 (1.18–1.94)
Foot problems (yes/no) (n=1362)	27.9	1.22 (0.93–1.60)
Poor or very poor self-perceived health (vs. fair/ good/excellent) (n=1365)	37.5	1.42 (1.11–1.83)
Hospital admission in the past 6 months (yes/no) (n=1364)	9.5	1.33 (0.89–1.98)[b]
Falls in the previous year ≥ two (vs. < two) (n=1360)	14.2	4.22 (3.08–5.79)
Pain (yes/no) (n=1147)	30.2	1.81 (1.36–2.41)[b]
Body composition		
Body weight: women ≤ 62 kg (vs. >62 kg); men ≤ 70 kg (vs. >70 kg) (25th p) (n=1357)	25.1	1.45 (1.10–1.91)
Body height: women ≤156 cm (vs. >156 cm); men≤169 cm (vs. >169 cm) (25th p) (n=1356)	26.1	1.23 (0.93–1.62)
Body Mass Index ≤24 kg/m^2 (vs. >24) (n=1355)	24.0	1.10 (0.83–1.46)[b]
Activity and mobility		
Functional limitations ≥ three (vs. < three) (n=1348)	12.2	2.61 (1.86–3.67)
Performance test score ≤4(vs. >4) (range: 0–12) (20th p) (n=1321)	21.3	2.44 (1.84–3.24)
Grip strength: women ≤32 kg (vs. >32 kg); men≤56 kg (vs. >56 kg) (20th p) (n=1344)	17.1	2.32 (1.71–3.13)
Physical activity ≥ three activities in the last 2 weeks (vs. < three activities in the last 2 weeks) (range: 0–6) (25th p) (n=1310)	26.9	1.36 (1.03–1.79)
Psycho-social functioning		
Cognitive impairment (MMSE score <24 vs. ≥24) (range: 0–30) (n=1363)	10.0	1.45 (0.99–2.14)
Depression score (CES-D ≥16 vs. <16) (range: 0–60) (n=1337)	14.4	1.83 (1.32–2.52)
Fear of falling score (FES ≥1 vs. 0) (range: 0–30) (50th p) (n=1246)	52.0	1.90 (1.45–2.49)
Loneliness score ≥5 (vs. <5) (range: 0–11) (80th p) (n=1364)	19.1	1.47 (1.09–1.97)
Living alone (yes/no) (n=1362)	38.6	1.14 (0.78–1.67)[b]
Life style factors		
Alcohol use ≥18 consumptions per week (vs. <18 consumptions per week) (80th p) (n=1363)	20.4	1.23 (0.92–1.65)
Current smoker (yes/no) (n=1364)	18.1	0.96 (0.70–1.32)[b]
Biochemical markers		
SHBG ≥44.5 nmol/l (vs. <44.5 nmol/l) (50th p) (n=1244)	49.1	1.46 (1.13–1.89)
IGF-1 ≤10.3 nmol/l (vs. >10.3 nmol/l) (25th p) (n=1242)	24.7	1.33 (0.97–1.82)
25(OH)D ≤25 nmol/l (>25 nmol/l) (10th p) (n=1243)	10.0	1.45 (0.97–2.17)
Albumin ≤42 g/l (>42 g/l) (50th p) (n=1248)	52.9	1.32 (1.02–1.71)
Other potential fall-related predictors		
Dogs or cats in household (yes/no) (n=1365)	17.4	1.23 (0.90–1.69)
Special adjustments in house (yes/no) (n=1364)	27.6	1.33 (1.02–1.74)

[a]p, Percentile; MMSE, Mini Mental State Examination; CES-D, Center for Epidemiologic Studies Depression Scale; FES, Falls Efficacy Scale; SHBG, sex hormone binding globulin; IGF-1, insulin-like growth factor; I; 25(OH)D, 25-hydroxyvitamin D

[b]Variables were not included in the multivariable logistic regression model when their prevalence was lower than 10%, when the number of missing predictors exceeded 10% or when they were not significantly (p<0.20) associated with recurrent falling in the univariate logistic regression analyses

Table 2 Risk profile of recurrent falling at the 3-year follow-up (n=1, 214)

Predictors	Regression coefficient	Score[a]	OR (95% CI)[b,c]
Constant	−2.19		
≥ Two falls in the previous year	0.71	4	2.03 (1.07–3.83)
Dizziness	0.77	4	2.16 (1.47–3.17)
Functional limitations (≥3)	0.53	3	1.70 (1.06–2.72)
Grip strength (women ≤ 32 kg; men ≤56 kg)	0.55	3	1.74 (1.19–2.54)
Body weight (women ≤ 62 kg; men ≤70 kg)	0.37	2	1.44 (1.05–1.99)
Fear of falling (score ≥1)	0.34	2	1.40 (1.01–1.93)
Dogs or cats in household	0.40	2	1.48 (1.03–2.14)
Education ≥11 year	0.21	1	1.23 (0.85–1.78)
Alcohol use (≥18 consumptions per week)	0.11	1	1.12 (0.71–1.76)
Alcohol use×education[d]	0.86	4	2.37 (1.18–4.73)
≥ Two falls in the previous year×fear of falling[e]	0.83	4	2.29 (1.04–5.04)

[a]The simple score is the regression coefficient multiplied by 5 and rounded off to the nearest integer

[b]OR, Odds ratio; CI, confidence interval

[c]All odds ratios are presented as increased risks

[d]Alcohol users (≥18 consumptions per week) with a high education level are at an increased risk of recurrent falling than those with a low education level, as was shown by an interaction between alcohol use and level of education. Alcohol users with less than 11 years of education receive a score of 1, whereas alcohol users with 11 or more years of education receive a score of 1+1+4

[e]Subjects with two or more previous falls who reported a fear of falling are at a higher risk of recurrent falling than subjects who did not report a fear of falling, as was shown by an interaction between previous falls and a fear of falling. Subjects who reported two or more previous falls with no fear of falling receive a score of 4, whereas subjects who reported two or more falls and a fear of falling receive a score of 4+2+4

The probability of recurrent falling ranged from 10% when none of these predictors was present to 97% when all predictors were present

Area Under the Receiver Operator Characteristics Curve (AUC) = 0.71 (95% CI: 0.67-0.74)

assessed by asking the respondent if, and how often, he or she fell in the year preceding the interview. Body weight was measured without clothes and shoes using a calibrated bathroom balance scale. Functional limitations were assessed with a questionnaire, which had been previously validated in The Netherlands [27], on the degree of difficulty in carrying out three activities of daily living (ADL), including climbing the stairs, cutting one's own toenails and using one's own or public transport. The scores on these activities were added together to give a total score that ranged from 0 (does not have any difficulties with the activities) to 3 (has difficulties with all of the activities). Grip strength was measured using a strain-gauged dynamometer (Takei TKK 5001, Takei Scientific Instruments Co, Tokyo, Japan). Respondents were asked to perform two maximum force trials with each hand. The maximum values of the right and left hand were added together and used as the final score [28]. Fear of falling was ascertained using a modified version of the Falls Efficacy Scale (FES) developed by Tinetti et al. [29]. Each participant was asked to report how concerned about falling he or she felt while carrying out each of ten activities of daily living (total score: 0–30). Instead of the original 10-point rating scale, the answers on each item were rated on a 4-point scale (0 = not concerned, 3 = very concerned). The presence of a dog or a cat in the household was determined by means of a questionnaire about pets. Alcohol consumption was assessed by asking the participant about the number of alcohol units he/she consumed per week [30].

To facilitate clinical interpretation, all categorical and continuous variables were dichotomised (yes/no). Cut-off points were chosen at a pre-established point (e.g., for CES-D and MMSE; see Table 1) or according to a clinical standard (e.g. orthostatic hypotension). When they did not exist, the risk gradients across quintiles and quartiles (20th, 25th, 50th, 75th and 80th percentile) were examined, and the most optimal cut-off was chosen, i.e. the cut-off point with the smallest log likelihood value [31]. Sex-specific cut-off points were determined for body weight, body height and grip strength because these measures are generally higher in men than in women (see Table 1).

Statistical analyses

To select predictors that could be used to identify subjects at an increased risk of falling, the analysis was performed in four stages. First, the frequency and prevalence of each potential predictor was calculated. Predictors with a prevalence of less than 10% or predictors of which the number of missing values exceeded 10% were excluded. Second, univariate logistic regression analyses were carried out with recurrent falling as the dependent variable and each of the potential predictors as the independent variable. The results are presented as odds ratios (ORs) with 95% confidence intervals (CIs) (Table 1). Predictors showing an association of $p<0.20$ for the Wald-test were included in the third phase of the analysis. In this phase, all eligible variables were entered simultaneously in a multivariable backward logistic regression model. If two potential predictors were highly correlated with each other (Spearman correlation ≥0.40), preference was given to the one that was the easiest to measure. Variables were sequentially deleted from the initial model on the basis of lack of significance ($p<0.05$) in the likelihood ratio-test. In the final phase, all possible interaction terms between variables in the final model were taken into consideration in order to increase the predictive value of the final model. However, only the interaction terms that significantly improved the model were included (see Table 2).

Subsequently, the probability of recurrent falling was calculated using the following formula:

$$P_{fall} = \frac{\Omega}{1+\Omega} = \frac{e^{(\beta_0+\beta_1 \cdot x_1+\beta_2 \cdot x_2+.....+\beta_n \cdot x_n)}}{1+e^{(\beta_0+\beta_1 \cdot x_1+\beta_2 \cdot x_2+.....+\beta_n \cdot x_n)}}$$

where P is the probability of recurrent falling, β_0 s the constant and β_1, β_2 and β_n represent the regression coefficients for each of the predictors x_1, x_2, x_n [31]. Using the predicted probabilities, a Receiver-Operator Characteristic (ROC) curve, which is a plot of the sensitivity against 1–specificity, was constructed to evaluate the discriminative qualities of the risk profile. The area under the ROC curve (AUC) measures the concordance of predictive values with actual outcomes in rank order, with an AUC of 0.5 reflecting no predictive power and an AUC of 1.0 reflecting perfect prediction [29]. The goodness-of-fit of the model was tested using the Hosmer-Lemeshow test [31]. To enable health care professionals to easily compute a risk score, we transformed the regression coefficients of the predictors in the final model (multiplied by five and rounded off to the nearest integer) into simple scores that can be added up to obtain a (global) total risk score.

Finally, the predictive performance of the risk profile to predict short-term risk of falling and fracture risk was examined. To examine the ability of the predictors of the final risk profile to predict short-term falling, logistic regression analysis with two or more falls at 1 year of follow-up (vs. zero or one fall) was performed. A Cox proportional-hazard regression model was used to estimate the ability of the fall risk profile to predict the risk of any fracture. Because the number of fall-related fractures at the 3-year follow-up was quite low (n=87), the time until the first fracture within 6 years of the follow-up was used as an outcome measure to increase the statistical power. The duration of follow-up was recorded for each respondent from the date of enrolment in the study to the date of the first fracture, the date of death or the date of the last follow-up.

Data were analysed using the software package SPSS ver. 9.0 for Windows (SPPS Inc., Chicago, Ill.).

Results

Sample

Among the 1421 eligible participants, 1365 (96%) were enrolled in this study. Of the 56 potential participants who did not take part in this study, 12 died before the follow-up started, eight had severe physical or cognitive problems, 35 refused and one was lost to the follow-up. Following an adjustment for age, it appeared that, with respect to the participants, the non-participants were living in rural areas significantly more often than in urban areas, had more often functional limitations, reported lower self-perceived health, had lower physical performance, a lower level of physical activity and were more often cognitive impaired (Chi-square, p<0.05). The sample included 667 (48.9%) men and 698 (51.1%) women. The mean age (in 1995/1996, at the time of the interview) was 75.3±6.4 years (range: 64.8–88.6).

Fall and fracture follow-up

Within the 3-year follow-up, 2570 falls were reported by 55.3% of the respondents: 21.9% reported one fall, 12.6% reported two falls and 20.9% reported three falls or more. A total of 174 of the women (24.9%) and 163 men (24.4%) fell at least twice within a 6-month period; these respondents were defined as ‘recurrent fallers’. In this same period, 5.5% of the respondents reported 87 fractures as a consequence of a fall, including 20 hip fractures, 21 wrist fractures and seven humerus fractures. Recurrent fallers had a fall-related fracture more often than those who were not defined as recurrent fallers (11.9% vs. 3.4%; OR: 3.8; 95% CI: 2.3–6.1). Of the 1365 respondents, 1092 (80%) completed all 12 three-month periods of the ‘fall’ follow-up. Of the 273 persons with one or more 3-month periods missing from the ‘fall’ calendar, 97 (35.6%) participated in the study for one to four periods, 60 (22%) participated for five to eight periods and 116 (42.5%) participated for 9–11 periods. The respondents with one or more missing fall calendar periods reported fewer falls (mean: 1.7; SD: 4.9 vs. mean 1.9; SD: 4.0 for the group with a complete 12-period follow-up) and were less often defined as a recurrent faller (20.9% vs. 25.9%, respectively). All of these respondents were included in the analyses to guarantee external validity. Table 1 shows the prevalence and the odds ratios of the potential predictors measured in relation to recurrent falling. As can be seen, most of variables were associated with recurrent falling in univariate analyses.

All variables with a prevalence of 10% or higher that were associated with recurrent falling (p<0.20) were entered into a multivariable regression model. The variables included in the final risk profile were: two or more previous falls, dizziness, functional limitations, weak grip strength, low body weight, fear of falling, the presence of dogs/cats in the household, a high education level, the drinking of 18 or more alcoholic consumptions per week and two interaction terms (high education × 18 or more alcohol consumptions per week and two or more previous falls × fear of falling) (see Table 2). The probability of recurrent falling ranged from 10% when none of these predictors was present to 97% when all predictors were present. The Hosmer-Lemeshow goodness-of-fit test for the multiple logistic regression was not significant (p=0.56), indicating that the model fits the data well.

The predictors included in the profile can be used to calculate an individual risk score for recurrent falling. To enable health care professionals to easily compute a crude risk score, the regression coefficients were transformed into a simple score. This score ranged from 0, when none of the predictors was present, to 30, when all predictors are present.

Figure 1 shows the probability of recurrent falling per point increase in the total fall risk score and the prevalence of these scores. A subject with no predictors had a 10% probability of becoming a recurrent faller, whereas the probability was 97% in those subjects who were positive on all nine predictors. The prevalence decreased with an increasing risk score. Only 0.7% of the subjects had a score of 20 or higher.

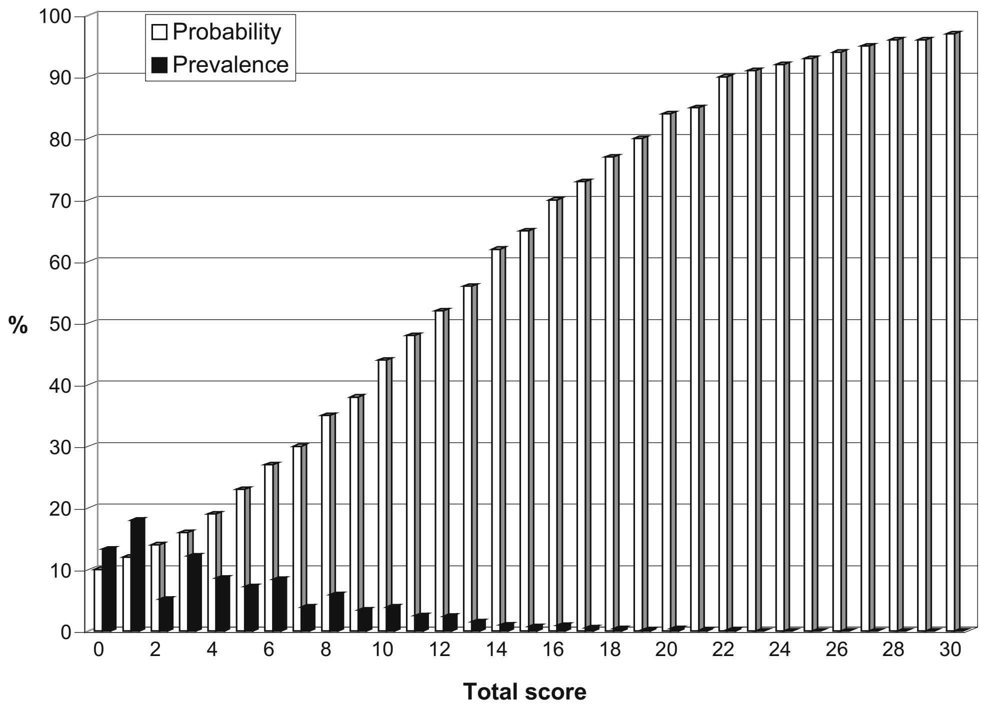

Fig. 1 The probability of recurrent falling per point increase in the total risk score and the prevalence of these scores. The *white columns* indicate the estimated probability of becoming a recurrent faller (≥2 falls within a 6-month period) per point increase in the total risk score. The *black columns* indicate the prevalence of the scores

How Fig. 1 can be used is demonstrated by the following case history:

A woman who graduated from university, drinks 20 glasses of wine per week, reported two falls within the past year and cares for a dog has a probability of becoming a recurrent faller of:

$$P\ falls = e^{-2.19+0.21+0.11+0.86+0.71+0.40} / 1+e^{-2.19+0.21+0.11+0.86+0.71+0.40} = 53\%$$

When using the risk score, one will find a total score of 1 (education) + 1 (alcohol use) + 4 (education×alcohol use) + 4 (two or more falls in the previous year) + 2 (presence of a dog or cat) = 12. As can be seen from Fig. 1, this score correlates to a probability of recurrent falling of 52%.

Table 3 presents the diagnostic and predictive values of the risk profile for different cut-off points. The data show that with a relatively low cut-off score, the sensitivity is moderate, and the specificity is low; with an increase in the cut-off score, the sensitivity decreases, whereas the specificity increases. The maximum summative score of sensitivity and specificity was reached at a score of 5 points. At this score, 35.7% of the sample are included in the high-risk group. A score of 5 or higher implies that there is a 38.6% probability of recurrent falls, whereas a score of 4 or lower implies a 15% probability of recurrent falls. The risk of recurrent falls in the total study sample is 24.9% (prior probability). The positive predictive value (PV) at a cut-off score of 5 is 38.6%, and the negative predictive (PV–) value is 85.1%.

Fig. 2 shows a ROC curve for the risk profile of recurrent falling. The area under the curve (AUC) is 0.71 (95% CI:

Table 3 Diagnostic values of the risk profile at different cut-off points in the total risk score[a]

Cut-off in the total risk score[a]	Percentage at high-risk group	Sensitivity (%)	Specificity (%)	∑[b] (%)	PV+[c] (%)	PV–[d] (%)
0 vs. ≥1	86.7	94.3	15.7	110	25.4	90.6
0–1 vs. ≥2	68.7	84.5	36.1	121	28.7	88.4
0–2 vs. ≥3	54.8	75.3	51.5	127	32.0	87.2
0–3 vs. ≥4	43.2	66.4	63.8	130[+]	35.8	86.2
0–4 vs. ≥5	35.7	59.0	71.4	130[+]	38.6	85.1
0–5 vs. ≥6	28.6	50.2	78.0	128	40.9	83.7
0–6 vs. ≥7	24.4	45.2	81.9	127	43.2	83.1
0–7 vs. ≥8	20.8	40.6	85.3	126	45.6	82.5
0–8 vs. ≥9	15.2	33.9	90.4	124	51.9	81.8
0–9 vs. ≥10	13.2	31.1	92.3	123	55.0	81.5
0–10 vs. ≥11	9.5	25.1	95.3	120	61.7	80.7
0–15 vs. ≥16	2.1	7.0	99.5	107	80.0	77.9

[a]The simple score is the regression coefficient multiplied by 5 and rounded off to the nearest integer
[b]∑=sum of sensitivity+specificity; [+]maximum ∑
[c]PV+, Positive predictive value
[d]PV−, Negative predictive value

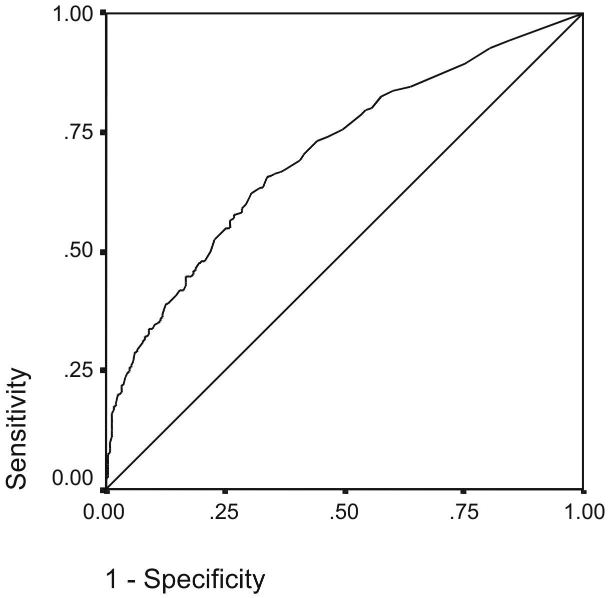

Fig. 2 Receiver-operator characteristic curve of the risk profile for recurrent falling; area under the curve (AUC)=0.71 (0.67–0.74)

0.67–0.74), indicating that 71% of the participants are classified correctly.

To examine whether the profile can be used to predict short-term recurrent falling, we tested the performance of the risk profile against recurrent falling (two or more falls) during the first year of follow-up as an outcome measure. The cumulative incidence of recurrent falls during the1-year of follow-up was 11.4% [7]. Of the predictors included in the risk profile for recurrent falling at the 3-year follow-up, dizziness, weak grip strength, the presence of a dog and/or cat in the household and the interaction term two or more previous falls×fear of falling were also significant predictors of recurrent falls at the 1-year follow-up (Table 4). The probability of two or more falls in 1 year ranged from 4% when none of the predictors was present to 90% when all of the predictors were present. The Hosmer-Lemeshow goodness-of-fit test for the multiple logistic regression was not significant (p=0.94), indicating that the model fits the data well. The AUC was 0.72 (95% CI: 0.67–0.77). When the two interaction terms were not included, two or more previous falls (OR = 4.11; 95% CI: 2.66–6.34), dizziness (OR = 1.64:1.00–2.73), weak grip strength (OR = 1.86:1.14–3.02) and the presence of dogs/cats in the household (OR = 2.27; 95% CI: 1.45–3.56) were the strongest predictors.

A total of 116 (8.5%) respondents reported one or more fall-related fracture(s) within the 6-year follow-up period. Of the predictors included in the risk profile for recurrent falling at the 3-year follow-up, only functional limitations was a significant predictor of fracture risk (Table 5). The probability of any fracture ranged from 4% when none of the predictors was present to 39% when all predictors were present. In the outcome measure, censoring due to mortality and loss due to follow-up had to be taken into ac-

Table 4 Risk profile of recurrent falling at one-year follow-up (n=1214) according to logistic regression analysis

Predictors	Regression coefficient	OR (95% CI)[a,b]
Constant	−3.13	
≥two falls in the previous year	0.64	1.89 (0.81–4.40)
Dizziness	0.52	1.68 (1.00–2.83)
Functional limitations (≥3)	0.39	1.48 (0.81–2.71)
Grip strength (women ≤ 32 kg; men ≤56 kg)	0.65	1.92 (1.17–3.14)
Body weight (women ≤ 62 kg; men ≤70 kg)	0.32	1.38 (0.89–2.14)
Fear of falling (score ≥1)	0.09	1.09 (0.68–1.75)
Dogs or cats in household	0.81	2.25 (1.43–3.54)
Education ≥11 year	0.08	1.09 (0.65–1.82)
Alcohol use (≥18 consumptions per week)	−0.15	0.86 (0.43–1.72)
Alcohol use × education	0.87	2.43 (0.90–6.51)
≥2 falls in the previous year × fear of falling	1.15	3.15 (1.16–8.55)

[a]OR, Odds ratio; CI, confidence interval
[b]All odds ratios are presented as increased risks
The probability of two or more falls in one year ranged from 4% when none of the predictors was present to 90% when all predictors were present
Area Under the Receiver Operator Characteristics Curve (AUC) = 0.72 (95% CI: 0.67-0.77)

Table 5 Risk profile of any fracture at six-year follow-up (n=1,214) according to Cox proportional hazard modeld[a]

Predictors	Regression coefficient	HR (95% CI)[b,c]
≥2 falls in the previous year	0.23	1.26 (0.49–3.24)
Dizziness	0.02	1.02 (0.57–1.79)
Functional limitations (≥3)	0.89	2.44 (1.41–4.23)
Grip strength (women ≤ 32 kg; men ≤56 kg)	0.26	1.29 (0.76–2.19)
Body weight (women ≤ 62 kg; men ≤70 kg)	−0.27	0.77 (0.46–1.28)
Fear of falling (score ≥1)	0.11	1.11 (0.70–1.76)
Dogs or cats in household	0.12	1.12 (0.66–1.91)
Education ≥11 year	−0.11	0.90 (0.52–1.54)
Alcohol use (≥18 consumptions per week)	0.19	1.20 (0.67–2.17)
Alcohol use education	−0.38	0.69 (0.22–2.18)
≥2 falls in the previous year fear of falling	0.33	1.39 (0.46–4.22)

[a]fractures of the head, fingers, toes and fractures caused by a traffic accident were excluded
[b]HR=Hazard Ratio; CI=confidence interval
[c]All hazard ratios are presented as increased risks
The probability of any fracture ranged from 4% when none of the predictors was present to 39% when all predictors were present
Area Under the Receiver Operator Characteristics Curve (AUC) = 0.62 (95% CI:0.57-0.68)

count; as a result, the AUC could not be correctly calculated. To obtain an indication, we performed a logistic regression analysis with fracture status at the 6-year follow-up instead of time until first fracture in order to calculate the AUC. The AUC was then 0.62 (95% CI: 0.57–0.68).

When the two interaction terms were excluded, two or more previous falls (OR=1.58; 95% CI: 0.96–2.62) and functional limitations (OR=2.46; 1.42–4.26) were the strongest predictors of fracture risk.

Discussion

The results of this 3-year prospective study showed that the risk of becoming a recurrent faller among community-dwelling older men and women can be predicted with a risk profile consisting of nine easily measurable predictors. The probability of recurrent falling ranged from 10% when none of these predictors was used to 97% when all of the predictors were used. The major strength of this study is its longitudinal design. As our study is the first one to date in which falls were prospectively recorded over a 3-year period, we were able to use a stringent definition of recurrent falling. A person was classified as a recurrent faller when he/she reported at least two falls within a 6-month period, a criterium which ensured that the study focussed on relatively frequent fallers. Because of the long follow-up (6 years), the percentage of recurrent fallers was large enough to examine many potential predictors. Furthermore, the risk profile was developed in a relatively large sample which was representative of Dutch community-dwelling senior citizens (65 years and older).

Our results have practical implications with respect to fall prevention. Any health care provider can easily perform the fall risk assessment. The predictors can be rapidly assessed by performing simple measurements using a dynamometer and a bathroom scale and by asking a few questions. When the total risk score has been calculated, the health care provider can determine from a figure (Fig. 1) just which patients are at high risk of becoming a recurrent faller. These patients can be advised to participate in a multi-factorial intervention programme, they can be referred to a physical therapist to improve muscle strength or balance or preventive measures can be taken to reduce the impact of a fall, such as the use of hip protectors [32] or walking aids [33].

The area under the ROC curve (AUC) was 0.71, which indicates that 71% of the subjects can be classified correctly using this risk profile. The sensitivity – i.e. the percentage of recurrent fallers who were classified by the risk profile to be recurrent fallers (true positives) – and specificity – i.e. the percentage of none- or once-fallers who were classified by the risk profile as non- or once-fallers (true negatives) – were assessed for different cut-off values in the total risk score. With a cut-off score of 5 (scores of 0–4 vs. 5 or higher), the sensitivity and specificity are 59% and 71.4%, respectively, which means that 41% of the recurrent fallers are not included in the high-risk group and 38.6% of the none- or once-fallers are included in the high-risk group. With a cut-off score of 9 (scores of 0–8 vs. 9 or higher), the sensitivity is moderate (33.9%), and the specificity (90.4%) is high. The most appropriate cut-off value depends on the relative costs of 'case finding' and the intervention strategy to prevent falls [34]. If the risk profile is used to select elderly for participating in preventive measures, such as an exercise programme with balance and strength training, a cut-off point ensuring a relatively high sensitivity is needed so that most of the older persons who will become future recurrent fallers are identified. In this group, the intervention may be very effective. In contrast, when the risk profile is used to select elderly for further extensive diagnostic testing in a hospital (for example, to identify underlying causes of falling in a fall prevention clinic), a high specificity (i.e. a cut-off score of 8 or higher) is needed to ensure that non- and once-fallers will not receive a tiring and costly examination by geriatricians and other medical specialists.

In line with our findings, other large studies have identified previous falls, impaired mobility, low muscle strength and dizziness as predictors in risk profiles [5–7, 16–18]. In a earlier study using the same LASA data [24], a classification tree was developed consisting of 11 groups differing in risk. Although, the statistical technique that was used in that previous study – Tree-Structured Survival Analysis – and the outcome measure were different from this study, two or more falls during the preceding year, functional limitations and regular dizziness were also identified to be the most important predictors. Further, in line with our present findings, a high level of education and alcohol use were also identified as predictors. However, none of the other studies of high methodological quality identified a high education level, alcohol use, low body weight, fear of falling and the presence of a pet as predictors of recurrent falling.

Some limitations of this study should be mentioned. First, this model has not yet been validated in another population. To validate the risk profile, its predictive ability has to be examined prospectively. Ideally, the risk profile must be administered at baseline in a cohort of elderly people who subsequently record falls prospectively. At the end of the follow-up, the incidence of falling should be compared to those with a low and high risk at baseline. A final step, and the major clinical challenge, is to assess whether an intervention strategy focussed on subgroups of older people with a high risk of falls, which were identified with the risk profile constructed in this study, does indeed reduce the number of fallers and patients with fractures. To determine the answer to this question, randomised controlled clinical trials are needed. We are currently participating in a study that is addressing these issues. Second, because this risk profile was developed in a group of relatively healthy community-dwelling senior citizens aged 65 years and older, this risk profile cannot be generalised to institutionalised or frail older people.

In conclusion, based on the data obtained in this 3-year prospective study, we have constructed a fall risk profile that includes nine predictors. Because this risk profile is easy to use, it would appear to be a suitable tool for the identification of community-dwelling elderly with a high risk of recurrent falling.

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